# 7. UNCERTAINTY REDUCTION: PLANNING AND IMPLEMENTING DATA COLLECTION

## Introduction

As noted in the previous section, uncertainty can be managed through reduction or mitigation. Traditionally, reduction through data collection has been the default approach. Indeed, over time, the investigation phase of environmental restoration has become a dominant element of every project. This in turn has led to the proliferation of sequential data collection activities including:

- Preliminary Assessment;
- Site Inspection;
- Expanded Site Inspection;
- Remedial Investigation (Often divided between operable units, broken into phases, and/or subdivided by soil, groundwater, background, and ecological surveys);
- Feasibility Study investigation;
- Treatability Study; and
- Remedial Design investigation.

While each of these activities may be necessary for any individual site, rarely are all required. There is no mandate to conduct specific activities beyond those needed to answer the two basic environmental restoration questions:

> Is there a problem?
> If there is a problem, what should be done about it?

As a consequence, streamlining efforts such as SACM and SAFER included initiatives to combine data collection elements and focus them in a manner that would reduce the generation of unnecessary information.

This chapter discusses approaches to focus and streamline data collection such as the DQO process and dynamic decision making. These techniques have proven valuable both in assuring the utility of data that are collected and in minimizing the collection of data for which there are no uses relative to the primary mission of environmental restoration.

## Data Needs Vs Data Gaps

The saying, "If a little is good, a lot is better," does not necessarily hold for data collection. Although more data may help better articulate a problem or may improve the ability to select a course of action, the additional data collection activity requires time and, therefore, delays implementation of the response.

Hence, data must materially affect the quality of the decision being made if they are to justify the added delays inherent in collecting them. It follows that it is prudent to make maximum use of available data, thus preventing what might otherwise be redundant efforts. One means of facilitating use of existing data is the Data Quality Assurance (DQA) process, which is applied to determine what decisions a data set can be used to support.

Where there are data gaps, it is important to first determine if they constitute data needs (i.e., do they resolve significant uncertainties). In order to accomplish that, it is best to determine how the data will be used and then what amount, kind, and quality of data are needed for that use. Typically, the utility curve for data (Figure 5-1) starts out on a steep upward slope and then rapidly levels off. Collecting additional data in the area of the horizontal asymptote is usually not productive. The mandate to determine the nature and extent of contamination is often over-interpreted. The intent is to require determination of the nature and extent of contamination to the degree necessary to write the problem statement and select the best response.

The CSM serves as a tool to help identify unnecessary or unproductive data collection efforts. Data associated with incomplete or nonviable pathways are unnecessary and can be eliminated from plans. Conversely, data to complete knowledge of viable pathways is important.

There are high priority data needs when a problem is uncertain, but likely to exist, which involve potential ongoing human and/or ecological exposure to unacceptable risk. Proposed data should be able to demonstrably improve the ability to write the problem statement. In other words, the investigation should target those areas of uncertainty that currently prevent completion of the problem statement.

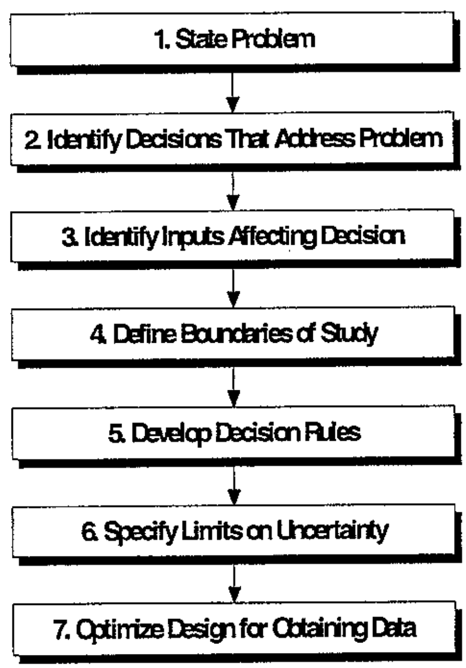
There are also data needs where there is a known problem, but there is uncertainty as to the response that should be made. In this case, data needs are associated with information required to finalize selection and design of the preferred corrective action. This is a very targeted effort. Each proposed data point should be challenged to see how or why it would affect the decision to select a preferred remedy or its design. If it will not, it is not required. For example, if a pump and treat or permeable treatment barrier remedy is the likely strategy and the perimeter of the plume has been mapped, additional wells inside the plume will not likely change the selection or design unless a condition that would be a fatal flaw for pump and treat is suspected (e.g., presence of DNAPL). Since the permeable treatment barrier can contain DNAPL and the pump and treat remedy cannot, the uncertainty over the presence of DNAPL may be managed by selection of the more robust alternative without having to reduce the uncertainty further. In this case, the bias towards uncertainty mitigation (as opposed to reduction) reflects the cost and limited effectiveness of technologies capable of locating or confirming the presence of DNAPL.

Similarly, there is often a desire to better map soil slated for exhumation, but if there are no capacity concerns, the data will not change the decision to excavate. In essence, data needs arise from fatal flaws or key design parameters specific to the technologies being evaluated.

## Planning Data Collection

Identifying and defining the decisions to be made is an essential part of the planning process and is performed through application of the DQO process. The DQO process is comprised of seven steps that are shown schematically in Figure7-1. Each of these steps and their application to planning and implementing data collection is discussed below.

**Figure 7-1: Steps in the DQO Process**




1. State the Problem. Stating the problem should be a simple description of the issues at the site that are cause for concern. The problem statement should be brief and should identify the source, and the potential to result in unacceptable human health or ecological risk as discussed in Chapter 3.

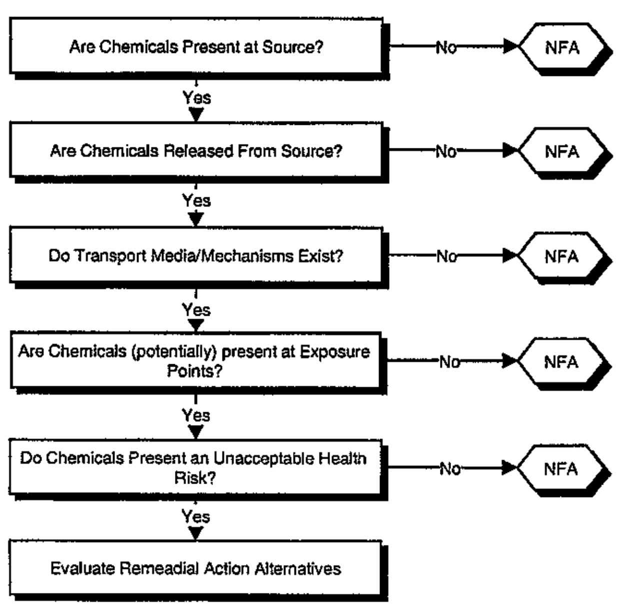
2. Identify Decisions that Address the Problem. A significant part of identifying decisions is accomplished by using a CSM as discussed in Chapter 6. Many forms of the CSM are appropriate to identify the pathways by which human or ecological receptors can be exposed to chemicals released from the AOC.

CSMs are used to identify decisions to be made about the potential chemical transport pathways. When a transport pathway is incomplete, there is no exposure or risk to human or environmental receptors that can result in an adverse effect.

The next step is to identify and define the decisions that are related to the CSM that will support resolution of the problem statement. These decisions can be specific or generic. The approach to defining the decisions should make more use of the CSM and the decisions should be related to the problem statement and site-specific conditions. Site-specific conditions may include current and future land use.

Generic decisions can be identified for each chemical transport pathway, as shown schematically in Figure 7-2 for a landfill. A typical decision for a landfill source may be, "Is a landfill present at the exact identified location?" Note that the exact location of the landfill does not need to be known to evaluate releases from the landfill. Decisions for determining whether or not a specific release mechanism exists can be identified. A basic decision to be made may be stated as, "Are contaminants being released in amounts that are potentially harmful to human health or the environment?" The need to evaluate a specific release mechanism depends on many factors, including the condition of the landfill cover and the specific contaminants potentially present in the source. For example, the suspension (wind erosion) release mechanism pathway would not be evaluated if the actual waste materials were covered with soil. In addition, the volatilization pathway would not be evaluated if it were known that the source contained only non-volatile components (construction debris).

**Figure 7-2: Generic Landfill Decisions**

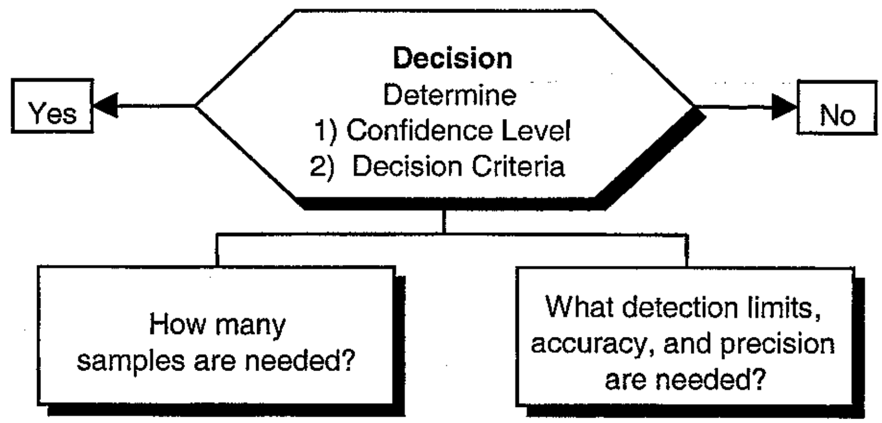


Pathway-specific decisions are also identified for transport media in each chemical transport pathway. This type of decision can be expressed as, "Are chemicals being transported in concentrations that are potentially harmful to human health or the environment?" A final decision to be made relates to the potential exposure of receptors, and may be stated as, "Are contaminant concentrations at identified exposure points harmful to human health or the environment?" If the answer is yes, the PMT proceeds to select the remedial alternative.

It is important that each decision is stated so that it can be satisfied with a yes or no answer. In fact, the PMT should formulate decisions that can be answered yes or no as a step in identifying data needs. The potential action that will be taken when the decision is answered must also be explained in the diagram and text. For example, if the decision is made that there is a source, the next step is to collect data to evaluate the presence of a release mechanism. The data for these two decisions can be collected in a single field mobilization effort. If the data support the decision that there is not a source, there is no further action, i.e., evaluation of a release mechanism, even though the data are collected, would not be done. When a no further action decision is made, there is no additional data collection or data evaluation for the specific pathway being evaluated.

The input to be considered in defining a decision is shown schematically in Figure 7-3. The decision in Figure 7-3 could represent any of the generic decisions illustrated in Figure 7-2 related to source, release mechanism, transport, exposure, risk or remedy selection (e.g., Are chemicals being leached from soil?). It is necessary to specify the confidence level for the decision so the number of samples, accuracy, and precision can be determined. The decision criteria must also be identified to assure proper selection of methods to support the required detection limits. When an answer can be given for the decision that is not a yes or no, the decision is not adequately defined to plan data collection. Poorly defined or undefined decisions most often lead to the need for additional data collection regardless of the outcome of the data collected. When decisions are identified that cannot be clearly answered yes or no, the DQO process must continue until an appropriate decision (one that can be answered only yes or no using data that could be collected) is defined. Defined decisions that cannot be answered only yes or no should be modified or separated into more than one decision. This will ensure that any additional data needed to meet project objectives will be identified in the Sampling and Analysis Plan (SAP).

## Figure 7-3: Typical Decision Process




3. <u>Identify Inputs that Affect Decisions</u>. This step in the process identifies the specific data needed to support decisions. For example, to identify inputs for the "are there chemical releases?" decision (Figure 7-2) and the pathway being considered is infiltration or percolation of chemicals from a landfill site, a likely input would be chemical concentrations in subsurface soil beneath (or adjacent to) and "down gradient" of the landfill source. The data input is chemical concentration in subsurface soil and the location of the sample both horizontally and vertically. The resulting input would be, for example, to collect data for samples adjacent to the source at a depth of five feet below the disposed wastes.

4. <u>Define Study Boundaries</u>. There are many study boundaries to be considered. The primary example of a study boundary given in EPA's DQO guidance is the level of funding. Other boundary conditions include; physical limitations of sampling, time constraints (agency schedule), materials migrating on site from off-site sources, agency policy, public opinion, Army policy, and permission to sample off-site locations not owned by the Army. All potential boundary conditions should be evaluated when the SAP is being prepared and it is best if the evaluations are actually included in the SAP.

5. <u>Develop Decision Rules</u>. Decision rules are developed from the decisions identified in Step 2. The decision rule can be considered a statement of the hypothesis to be tested. Data are collected to confirm or reject the hypothesis. For example, a decision in Figure 7-2 is, "are chemicals released from the source?" This decision can be changed to the form of a decision rule, which is an "If...then" statement. An example decision rule would be; "If a chemical is released from the source in concentrations greater than the decision criterion, then the transport media for this pathway will be investigated to determine if there is transport of chemicals. The decision criteria are generally numerical values related to the decision being made. Often the decision criteria are related to

concentrations that are protective of human health or the environment. Numerical decision criteria determine the quality of data that are needed to make the decision. These criteria can be health based screening levels (e.g., PRGs), MCLs, regulatory criteria for various media, negotiated criteria, or remedial design criteria for remedial design-related decisions. The decision criteria determine the accuracy and precision of the analytical measurement needed for each defined decision

When the decision rule is stated in a chemical- and sample-specific manner, the decision rule would be, "If the concentration of chloroform in subsurface soil samples collected at five feet below the source is greater than 20 mg/kg, then additional investigation will be performed to assess potential transport of chloroform by the shallow aquifer." The decision criterion (20 mg/kg in this example) would be a value that is protective of human health and the environment.

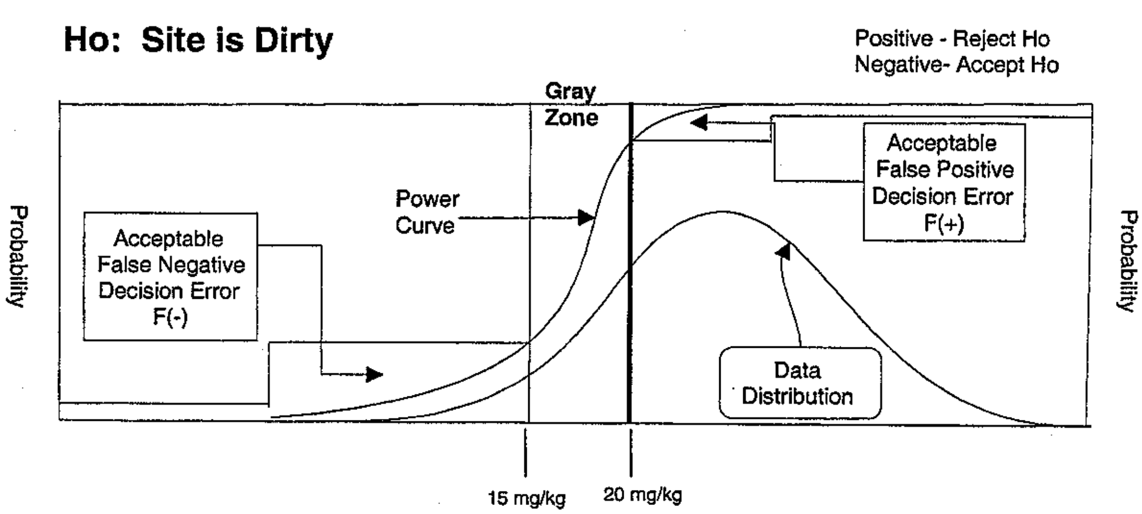
6. <u>Specify Limits on Uncertainty</u>. Initially, the PMT may not be comfortable acknowledging there is uncertainty in making decisions for an investigation. However, EPA's RI/FS guidance states that it is not an investigative objective to eliminate uncertainty, but to make defensible decisions. The confidence level needed for the defined decision is the "acceptable uncertainty" identified in EPA's DQO guidance. (Note. This use of the term uncertainty refers to the ability to make confident decisions i.e., the level of certainty that a decision is correct. This differs from the broader definition of uncertainty addressed by the fourth Principle.) The reality of an investigation is that it is not possible to collect enough data to be one hundred percent confident that the measured data statistic is identical to that of the true population. When the PMT defines acceptable uncertainty, it is important to understand that there is always uncertainty in measured data and decision making. In addition, the level of acceptable uncertainty is established for the <u>decision</u> being made, not for the collected data. The PMT must note that the entire population must be sampled when attempting to eliminate uncertainty, and even with that effort, measurement error and uncertainty still exist.

After the decision rule has been defined, the confidence level or acceptable uncertainty in each decision must be identified. Acceptable uncertainty is equivalent to feeling comfortable about a decision when it is based on collected or available data. Generally, less uncertainty (more comfort) is needed to support a no action alternative than an active remedial action. Two kinds of uncertainty are considered in planning data collection and making decisions. The most important uncertainty is called a *decision error* (probability of making an incorrect decision). The second uncertainty is that the collected data will not be within the concentration range needed for confident decision making and is related to the *Gray Zone*. The Gray Zone is the range of concentrations where decision errors <u>are</u> acceptable.

Figure 7-4 is a power curve diagram that illustrates the acceptable decision errors and the Gray Zone acceptable error for an investigation when the null hypothesis is that the site is contaminated. This hypothesis assumes the data distribution is at concentrations generally greater than the decision criterion (shown by the data distribution curve). A decision error for a truly contaminated site is to reject the null hypothesis and declare the site clean (this is a False Positive [F(+)] decision error). The consequences of an F(+) decision error are that an area would not be investigated further or remediated when it is potentially harmful to human health or the environment. A decision error for a truly uncontaminated or clean site is to accept the null hypothesis and declare the site contaminated (this is a False Negative [F(-)] decision error). The consequences of an F(-) decision error are that resources would be used to investigate and/or remediate a clean site and there would be no health-related benefits for human or ecological receptors.

The acceptable decision error and Gray Zone uncertainties are directly related to the question of "How many samples are needed?" Lower acceptable uncertainty requires more samples. The uncertainty in a decision is related to the quantity and quality of the data and to the magnitude of difference between the collected data and the decision criterion. For example, data sets with high variability (low quality) can be used to make very confident decisions, as will be explained later in this section.

**Figure 7-4: Power Curve Ho: Site is Dirty**



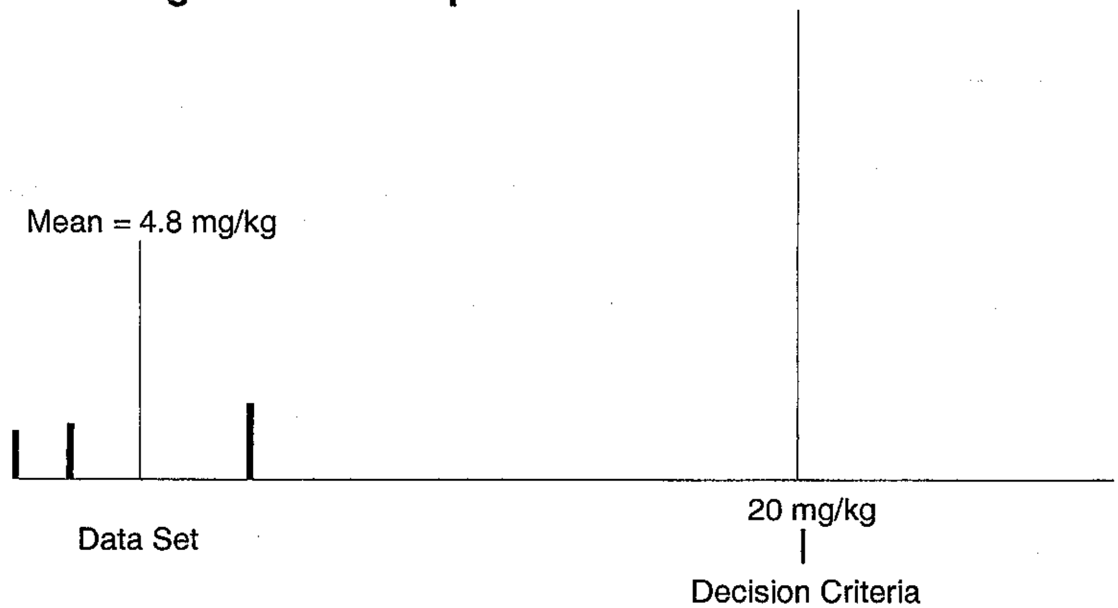

When identifying acceptable uncertainties the PMT must consider EPA's goal to protect health, which is to protect 95 percent of the exposed population. This results in an acceptable F(+) decision error probability of 0.05, which is appropriate when the site concentration is near the decision criterion. However, when the site concentration is much larger than the decision criterion, the consequences of an F(+) decision error are less acceptable. Therefore, as shown in Figure 7-4, the acceptable F(+) decision error is reduced to one percent at the higher concentrations. The PMT must document these consequences as part of the planning task.

Establishing a Gray Zone for the $H_o$ = the site is "dirty," assumes for data collection planning, that it is acceptable to clean up areas that may have concentrations less than the decision criterion (20 mg/kg). The gray zone shown in Figure 7-4 means that for planning purposes, those areas with subsurface soil concentrations greater than 15 and less than 20 mg/kg would be remediated. The acceptability of decision error within the Gray Zone acknowledges that substantial numbers of samples would be required to conclude that data within this zone are confidently less that the decision criterion.

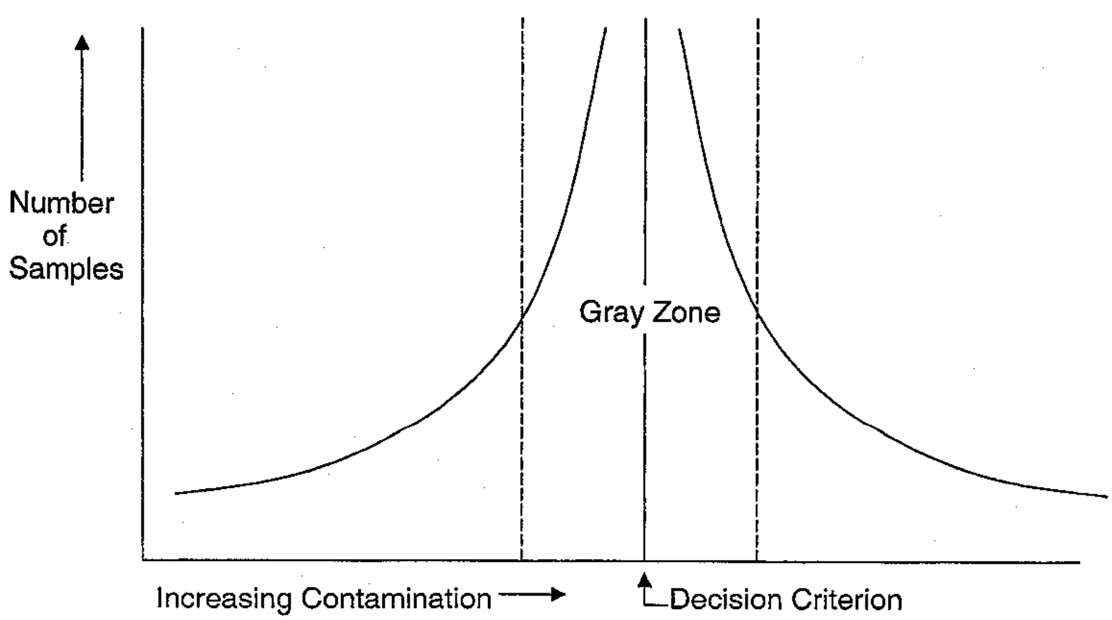
The width of the Gray Zone is not based on technical or scientific merit. It is derived by PMT consensus. For example, it is unlikely that the PMT would feel comfortable collecting as few as three or as many as 1,000 samples to support a single decision in a remedial investigation of a single source. However, because of their experience, PMT members may feel comfortable within the range of 15 to 30 samples. There is a similar comfort range for decision errors. F(+) errors may range from 0.10 to 0.01 probability and F(-) errors may range from 0.10 to 0.50 probability. These comfort ranges are difficult to document. However, it is necessary to reach agreement on the number of samples. This agreement can be documented in terms of acceptable decision error and Gray Zone width by using EPA's Decision Error Feasibility Trials (DEFT) software (http://www.epa.gov/crdlvweb/databases/datahome.htm). This software relates acceptable decision errors and Gray Zone width to the number of samples needed. This approach allows the PMT to communicate their SAP in terms of decisions being made and acceptable uncertainty.

As stated earlier, high quantity and quality data are not always required to make confident decisions. For example, one can have a minimal data set with a relatively large variance and still make a confident decision as shown in Figure 7-5. Because the mean of the data is very small compared to the decision criterion, one can be more than 95 percent confident that the site concentrations do not exceed the decision criterion. This highly confident decision can be made although one does not have a high confidence that 4.8 mg/kg represents the true average concentration in subsurface soil. The PMT's objective is to make confident decisions, not to be confident that the collected data are "truly" representative of the population being sampled.

## Figure 7-5: Compare Data To Decision Criterion

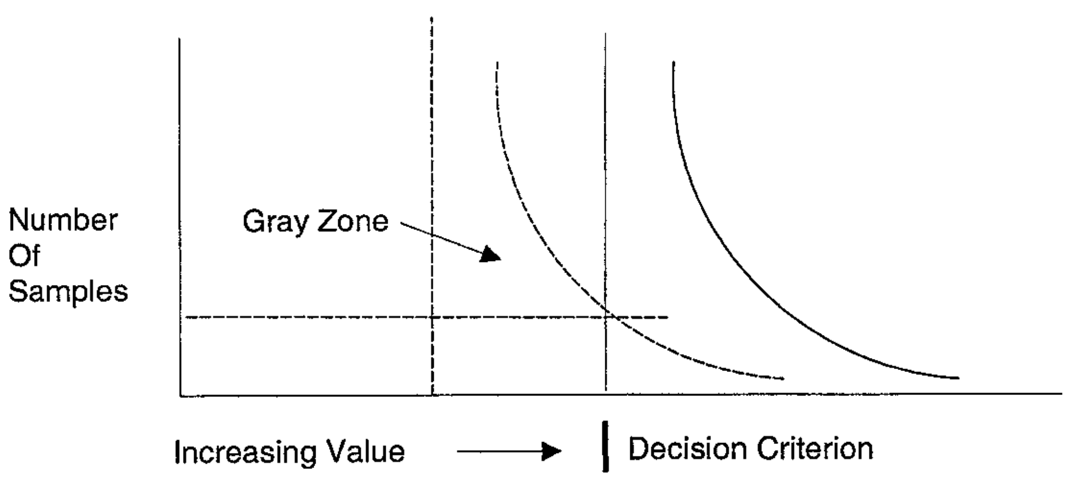



## Figure 7-6: Number of Samples



When the mean of the data set and the decision criterion become close to the same value, additional data are needed to keep the same level of confidence that the mean of the data set is greater or less than the decision criterion. The solid curve and decision criterion lines in Figure 7-6 show schematically how the number of samples increases as the mean (or other data statistic) approaches the decision criterion. The Gray Zone concept can also be explained using the dotted lines in Figure 7-7. The lower Gray Zone line becomes a pseudo decision criterion, which is used only for planning purposes (not decision-making). The intersection of the decision criterion, and the dotted curve shows the number of samples required (horizontal dotted line). Note that a wider Gray Zone results in fewer samples.

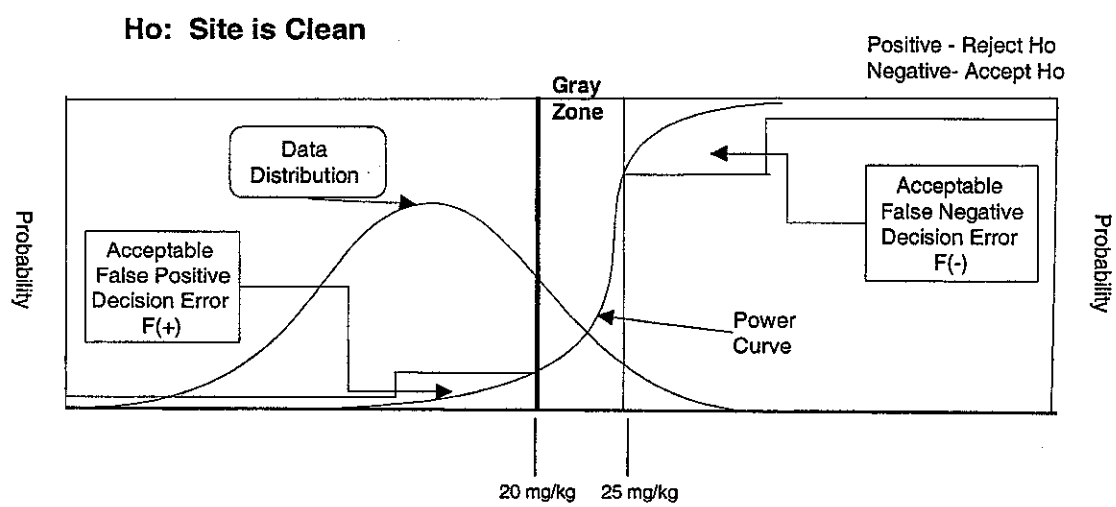
**Figure 7-7: Number of Samples - Gray Zone**




There are occasions when the PMT cannot reach consensus that past activities do or do not warrant investigation of an AOC. In these situations, if an investigation is planned, it is recommended that the null hypothesis used for the SAP is that the site is "clean." The power curve for this hypothesis is shown in Figure 7-8. For this hypothesis, the Gray Zone is to the right of the decision criteria because the consequences of remediating a clean site are more severe than potential human or ecological risk at a clean site. The data distribution is on the lower concentration side of the decision criterion with few concentrations greater than the decision criterion. This strategy acknowledges that a few modest exceedences of the decision criterion at a clean site will not result in an unacceptable risk. The upper Gray Zone concentration becomes the value for decision-making. Within the Gray Zone concentration range, decision errors are acceptable.

For the example shown in Figure 7-8, the consequences of missing subsurface soil at concentrations up to 25 mg/kg is acceptable, because there is no reason to believe that the site is contaminated and the data distribution is generally less than the decision criterion. For planning purposes this Gray Zone means that soil containing greater than 20 but less than 25 mg/kg would not be investigated further or remediated.

**Figure 7-8: Power Curve Ho: Site is Clean**




7. <u>Optimize Design for Obtaining Data</u>. After identifying the decisions, decision criteria, the input to support the decisions (data) and acceptable uncertainty, the approach to obtain the data can be optimized. Optimization examines the sampling strategy, sample location needs, sample number, analytical data for samples, etc., for each data use. The optimization process identifies potentially co-located samples and samples that can be used to obtain data that support more than one decision. The data set statistic used to compare to the decision criterion has a significant influence on the sampling strategy that is appropriate to collect the data. For example:

- A judgmental approach is appropriate if the maximum or minimum value detected are compared to the decision criterion;
- A random approach is appropriate if the mean (or a statistic representing the mean, e.g., 95 UCL) is compared to the decision criterion;
- A systematic approach is appropriate if the decision criterion is representative of a spatial characteristic of the area (exposure area); and

- A combination of the strategies can be used for specific decisions, for example a randomly located systematic approach is appropriate to compare the mean of an area with a decision criterion.

As plans are developed to collect the data necessary to resolve uncertainties selected for management through reduction, they are merged into a SAP. The SAP attempts to integrate the activities such that mobilization for field efforts can be minimized. As plans and protocol are merged, there may be opportunity to optimize through combination of samples, co-location of samples, and selection of more robust methods. The SAP provides an opportunity to take a systems view of the data reduction effort and eliminate redundancies or leverage synergies. With today's technologies there is no reason for characterization plans that require years to complete. By recognizing what is technically achievable, the PMT can identify viable alternatives to excessively lengthy investigation plans, thus meeting the objective to accelerate schedules.

## Dynamic Decision Making

Dynamic decision making and related approaches that employ a dynamic work plan identify data needs and methods, but leave specific quantities and samples open to selection as a result of interpretation of data as they are collected. This approach is enabled by field analytical and screening methods that provide real-time output. The EPA Technology Innovation Office has prepared the document: "Field Analytical and Site Characterization Technologies," EPA-542-R-97-012, which summarizes observations from 204 applications of new techniques at installations across the country. Methods are available for soil, water, air and soil gas samples containing a variety of contaminant types or specific chemicals (Figure 7-9). These methods can be applied in support of dynamic work plans.

## Figure 7-9: Dynamic Decision Making

| Technology | VOC | SVOC | Fuels | Inorganics | Explosives | Pesticides |
|---|---|---|---|---|---|---|
| Biosensor | | | | | S, W | |
| Colorimetric Strip | | | | S, W | S, W | |
| CP Mounted Sensor | S, W | S, W | S, W | | | |
| Fiber Optic Sensor | SG, W | W | W | | | |
| GC/Soil Gas | S, W, SG, A | S, W | S, W, SG | | | S, W |
| Immunoassay | S, W | S, W | S, W | S, W | | S, W |
| Hg Vapor Analyzer | | | | A | | |
| XRF | | | | S,W | | |

S--Soil
W--Water
A--Air
SG--Soil Gas

*Adopted from EPA 542-R-97-012

Dynamic decision making allows implementation of phased or conditional investigations that minimize mobilization activities and eliminate delays for sample turnaround, interpretation, and re-planning. It allows defined data values or relationships to serve as end points rather than a defined number of samples. This approach facilitates resolution of apparent contradictions in CSM or apparently anomalous data and minimizes problems with temporal equivalence.

For example, to determine the depth of chromium contamination prior to selecting an excavation alternative with a full laboratory sampling and analysis approach, the PMT would elect to prescribe a maximum sampling depth and analyze samples at 5-foot intervals. If the predetermined maximum depth were not sufficient, another mobilization for a subsequent, deeper boring(s) would be necessary. With a dynamic decision-making approach, the PMT could apply field x-ray fluorescence (XRF) for total chromium. The PMT would set a threshold value and continue downward until an agreed to number of successive depth samples below the threshold were obtained. In this way, the depth could be defined in a single campaign.

Field methods can expedite uncertainty reduction only if they are sensitive enough to answer the pending question at the level of significance relative to any operative thresholds. As such, they must have detection limits below the threshold value. For example, XRF may be helpful in addressing pathways associated with total chromium, but is not sensitive enough to address hexavalent chromium thresholds even when it is assumed that all chromium is hexavalent chromium.

The threshold value for a parameter varies with the use to which the data are being put. When quantification is the goal, the threshold may be a risk-based concentration, which can be very low. When the objective is delineation or targeting for subsequent, more sensitive analyses, the threshold may be higher. In the depth of chromium example, XRF screening would provide a good indication of distribution prior to excavation, while higher resolution laboratory analyses would be required for confirmation after excavation.

Laboratory confirmation may be advisable for some methods depending on use of the data and the reliability of the method. For instance, field XRF data should be calibrated with periodic samples sent off for atomic adsorption or inductively coupled argon plasma analysis in the laboratory to avoid misinterpretations due to matrix interference. Conversely, field gas chromatography on soil vapor samples may not need any further confirmation, especially if soil vapor extraction is the preferred remedy.

The PMT must determine the nature and frequency of confirmatory sampling. Frequency may be reduced if early results indicate close correlation between laboratory and field results. Conversely, the greater the variability and or deviation between the two data sets, the more important it will be to maintain a frequent cross check. In general, confirmation at the 10 percent level is a good starting point.

Pre-determined, documented decision rules provide the necessary basis to manage field-based characterization approaches, such as those applied with dynamic decision making. Decision rules specify (as necessary):

- Technique to be used;
- Procedures to implement the techniques;
- General areas and depths of characterization;
- Threshold values above which a decision is determined or additional considerations are triggered; and
- Contingencies or extended activities (as appropriate).

For example, "Samples will be taken in four compass directions at 100 feet spacing moving outward from the source area and vertically at 20 foot intervals. If concentrations display a downward trend and the last sample had less than 5 mg/kg TCE, then characterization on that vector can be terminated."

It is important to understand the logic behind an approach to identify minimum requirements and devise a plan that will fill those gaps at the desired level of confidence.

## Summary

Uncertainty reduction is accomplished by collecting data to fill specified data needs. Data needs are determined on the basis of consistency with the CSM and related problem statement (if one has been formulated). The DQO process provides a logical thought sequence to identify the minimum data required to proceed in answering relevant site questions fundamental to the environmental restoration project. The DQO process involves seven discrete steps:

1. State the Problem;
2. Identify Decisions that Address the Problem;
3. Identify Inputs Affecting those Decisions;
4. Define Study Boundaries;
5. Develop Decision Rules;
6. Specify Limits on Uncertainty; and
7. Optimize Design for Obtaining Data.

The availability of field analytical methods enables some data collection efforts to be accomplished with dynamic decision making wherein real-time results are obtained and utilized to direct subsequent efforts on the basis of pre-determined decision logic. The latter approach reduces cost and time requirements associated with sampling and analysis activities.